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THE EFFECT OF TERNARY INTERMETALLIC COMPOUNDS ON THE HEAT RESISTANCE OF DEFORMED ALUMINUM ALLOYS

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In one of the preceding works (1) the authors investigated the effect of the ternary compound E ($Mg_2Al_{12}Cr$) on the heat resistance of deformed aluminum alloys and demonstrated the possibility of obtaining alloys which are characterized by significant long-term resistance.

The present investigation is dedicated to the further development of work in this direction and has as its goal the determination of the high-temperature hardness of certain ternary intermetallic aluminum-containing compounds and an explanation of their effect on the short- and long-term resistance of extruded aluminum alloys.

Seven ternary intermetallic compounds were prepared according to a method described previously (2). Their composition according to the results of a chemical analysis and their extrusion parameters are shown in Table 1.

Table 1

Compositions and extrusion parameters of ternary intermetallic compounds

Compound	Composition, %								Extrusion temp, °C	Specific extrusion pressure, kg/mm2
	Cu	Mn	Ni	Mg	Zn	Cr	Si	Fe		
$Cu_2Al_{20}Mn_3$ (T)	15,68	19,7	—	—	—	—	—	—	650	32,5
Cu_3Al_6Ni (τ)	46,4	—	15,1	—	—	—	—	—	650	37,5
$Mg_4Zn_3Al_3$ (T)	—	—	—	26,0	52,2	—	—	—	460	43,3
$Mg_2Al_{12}Cr$ (E)	—	—	—	8,1	—	16,3	—	—	400	25,2
$Al_9Si_2Mn_4$ (T)	—	41,1	—	—	—	—	14,9	—	680	28,8
$Al_{60}Mn_{11}Ni_4$ (X)	—	24,7	8,9	—	—	—	—	—	700	39,7
Al_9FeNi (τ)	—	—	16,2	—	—	—	—	15,7	700	50,5

Before testing, the ternary compounds were made homogeneous by heating the $Mg_2Al_{12}Cr$ and $Mg_4Zn_3Al_3$ at 400° for 10 days and the others at 500°, after which the alloys were gradually cooled to room temperature over a 24 hour period.

A determination of the microhardness at different temperatures was made using the method of Academician A. A. Bochvar (3) on an apparatus developed at the IMASh of the Academy of Sciences USSR and the VIAM. The time of exposure to the indentor was 30 seconds and 60 minutes with a load of 50 g; the testing temperatures were 20° and 300°. The test data are shown in Table 2 in absolute units and in percentages; the hardness values are averages from four to five determinations.

The data in the following Table 2 are quite interesting, characterizing to a certain extent the long-term heat resistance of ternary compounds. The compound $Mg_2Al_{12}Cr$ (*E*) possesses the greatest long-term hardness but the coumpounds Cu_3Al_6Ni (τ), $Mg_4Zn_3Al_3$ (*T*) and Al_9FeNi (ɔ) decrease their high temperature hardness approximately twofold.

Table 2

Microhardness of ternary intermetallic compounds at 20° and 300°

Compound	Microhardness, kg/mm²						
	20°	300°					
	30 sec	30 sec	Decrease in hardness, absolute	Decrease in hardness, %	60 min	Decrease in hardness, absolute	Decrease in hardness, %
$Cu_2Al_{20}Mn_3$ (*T*)	421	404	17	4,0	302	102	25,3
Cu_3Al_6Ni (τ)	740	585	155	21.0	316	269	46,0
$Mg_4Zn_3Al_3$ (*T*)	345	225	120	34,8	101	124	55,0
$Mg_2Al_{12}Cr$ (*E*)	461	402	59	12,8	358	44	11,0
$Al_9Si_2Mn_4$ (*T*)	589	458	131	22,3	361	97	21,1
$Al_{60}Mn_{11}Ni_4$ (*X*)	343	307	36	10,5	231	76	24,8
Al_9FeNi (ɔ)	860	712	148	17,2	414	298	41,8

These data may serve as a useful guide for the development of heat-resistant alloys of the metal-ternary intermetallic compound type for use under conditions of long-term loading.

The hardness at various termperatures had been determined previously for certain ternary compounds (4). The results, in comparison to those obtained in the present study, were higher in all cases probably because in reference (4) a smaller load (10 g) was used on the indentor because of fear of disintegration. Our experiments showed that a load of 50 g, which made it possible to measure with greater accuracy, could be used even at 300° since at this temperature

all the ternary compounds studied are quite sufficiently ductile to exclude disintegration phenomena.

The substantial high temperature hardness of some of the ternary compounds studied made it possible to propose the possibility of using them for increasing the heat resistance of aluminum alloys.

In order to test this, 46 experimental alloy systems were prepared:

$Al—Cu_2\overline{Al_{20}}Mn_3$	with compositions up to	20%	of ternary compound
$Al—Cu_3Al_6Ni$	"	31%	"
$Al—Mg_4Zn_3Al_3$	"	32%	"
$Al—Mg_2Al_{12}Cr$	"	17%	"
$Al—Al_9Si_3Mn_4$	"	17%	"
$Al—Al_{60}Mn_{11}Ni_4$	"	16%	"
$Al—Al_9FeNi$	"	13%	"

The composition of the alloys is given in Table 3.

The ternary compounds in these alloys are found in equilibrium with the corresponding ternary solid solutions. For this reason the amount of alloyed elements in the alloys of certain systems does not quite correspond to the composition of the ternary compound; the percentage of the latter is calculated in such cases according to the content of the element present in least amount.

The solubility of various compounds in solid aluminum is not uniform. So, for example, the solubility of the compounds $Al_9Si_3Mn_4$ [5], $Al_{60}Mn_{11}Ni_4$ [6] and Al_9FeNi is quite insignificant in view of the fact that solid solution regions are practically absent in the corresponding ternary composition diagrams. Tempered alloys of these systems do not harden upon subsequent aging. In the system $Al—Cu_3Al_6Ni$ [8] a certain hardening appears upon aging, however the solubility of the ternary compound in aluminum apparently is also quite small; all alloys containing more than two per cent ternary compound after a 48-hour heat soak at 510° and subsequent tempering had a two-phase structure.

On the other hand, the solubility of the ternary compounds $Cu_2Al_{20}Mn_3$, $Mg_2Al_{12}Cr$ and $Mg_4Zn_3Al_3$ in solid aluminum increased noticeably with increased temperature. The values of the specific solubility of the alloying elements in the aluminum, according to the sections studied, are given in Table 4.

Table 3

Amount of alloyed elements in the alloys, % by weight

Alloy No	Cu	Mn	Alloy No	Cu	Ni	Alloy No	Mg	Zn	Alloy No	Mg	Cr	Alloy No	Si	Mn	Alloy No	Mn	Ni	Alloy No	Fe	Ni
1	2,27	3,37	7	0,99	0,48	15	0,24	0,72	22	1,95	0,05	28	0,34	0,84	35	0,75	0,33	41	0,30	0,23
2	2,40	0,62	8	1,80	0,73	16	1,73	4,76	23	2,00	0,14	29	0,38	1,09	36	1,22	0,65	42	0,48	0,46
3	2,74	0,84	9	2,99	1,11	17	2,42	6,52	24	2,24	0,24	30	0,72	1,72	37	1,76	0,79	43	0,72	0,66
4	2,90	1,50	10	3,95	1,40	18	3,35	8,68	25	2,30	0,63	31	1,22	3,20	38	2,74	1,17	44	1,22	1,39
5	3,88	2,04	11	5,65	1,69	19	4,16	11,0	26	2,72	1,18	32	1,62	4,30	39	3,42	1,45	45	1,70	1,65
6	4,58	3,96	12	7,21	1,93	20	5,74	14,5	27	3,66	2,12	33	2,15	5,65	40	6,94	1,70	46	1,83	2,15
			13	9,54	2,98	21	7,03	18,0				34	2,65	6,94						
			14	14,3	4,45															

Table 4

Greatest solubility of elements in solid aluminum for certain systems

System	Temperature °C	Specific solubility of alloyed elements,%
A —$Cu_2Al_{20}Mn_3$	400	Cu ≈ 1,4; Mn ≈ 0.1 [9]
Al—$Mg_2Al_{12}Cr$	500	Mg ≈ 2,0; Cr ≈ 0,3 [10]
Al—$Mg_4Zn_3Al_3$	300	Mg ≈ 1,5; Zn ≈ 3,8 [11]

The method for melting and extruding the experimental samples was described in reference (2). For testing the heat resistance of the extruded bars, Gagarin - type samples were cut, tempered and aged artificially before testing. The tempering temperature was selected to be 20°-30° lower than the solidus temperature, and varied from 420° to 600° for different alloys.

Only alloys of the $Al—Cu_3Al_6Ni$ and $Al-Mg_4Zn_3Al_3$ systems were aged; for these an effect of increased hardness upon aging had been observed earlier (2). Alloys of the first of these systems, after tempering, were heated for 60 hours at 180°; alloys of the second system were heated for 47 hours at 100°, which corresponded to the optimal aging conditions.

Determination of the heat resistance consisted of short term and long term tests under elongation at 300°. The short term tests were carried out by the standard method determining the resistance limit (σ_B) and the specific elongation (δ) lengthwise $l_0 = 5d$. Tests of long term resistance were carried out as a rule under a load of 4 kg/mm^2 with a determination of the time elapsing until fracture (τ) . The results are shown in Fig. 1-6. Each value determined was the average from three tests.

No diagrams are shown for the $Al—Al_9Si_3Mn_1$ system since the heat resistance of these alloys is quite low; their short term resistance at 300° was about 6 kg/mm^2 and elapsed time before fracture under a load of 3 kg/mm^2 was less than one hour for all of the samples.

It is possible to draw a number of conclusions from an analysis of the results obtained.

In all the systems studied the heat resistance of the alloys increased up to a certain limit of ternary intermetallic compound content.

In the $Al—Mg_4Zn_3Al_3$, $Al—Cu_2Al_{20}Mn_3$ и $Al—Mg_2Al_{12}Cr$ systems, which are characterized by noticeable solubility of the ternary compound in aluminum, a maximum long term resistance was reached at a particular composition. This maximum is found in alloys in whose structure there are, after tempering, solid solutions that can undergo dispersion hardening (which also explains their hardening effect on aging). At the long-term resistance test temperature (300°) such alloys (Nos. 4, 20 and 25) must have a heterogeneous twophase structure, according to the data of Table 4. This is in agreement with the characteristic regularities in heat resistance variation that were determined in references (12-14) where it was shown that alloys with maximum heat resistance at high temperatures are found in the region of unsaturated solid solutions, those with maximum heat resistance at average temperatures correspond to the area where the saturation limit has been reached

and those with maximum heat resistance at lower temperatures lie in the two-phase region of the composition diagram. Apparently alloys 4, 20 and 25 which we studied correspond to the last case since they show a maximum heat resistance while possessing a heterogeneous structure (Figs. 7, 8 and 9). [not shown].

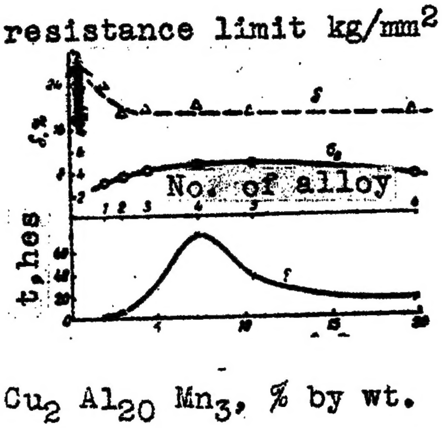


Fig. 1 - Relationship of the heat resistance of the alloys Al-$Cu_2Al_{20}Mn_3$ to composition. Tests were made of the short-term resistance at 350°, long-term resistance at 300° with a load of 4 kg/mn^2

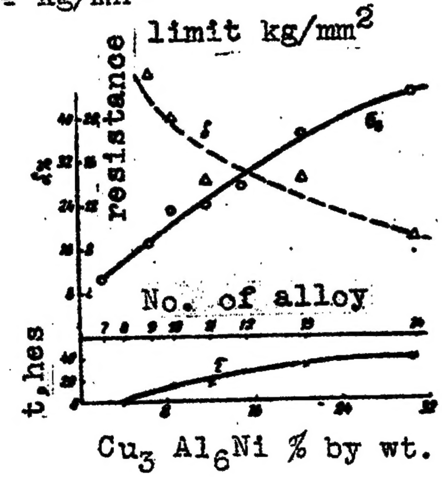


Fig. 2 - Relationship of the heat resistance of the alloys Al-Cu_2Al_6 Ni to composition. Tests were made of the short-term resistance at 300°, long-term resistance at 300° with a load of 4 kg/mm^2

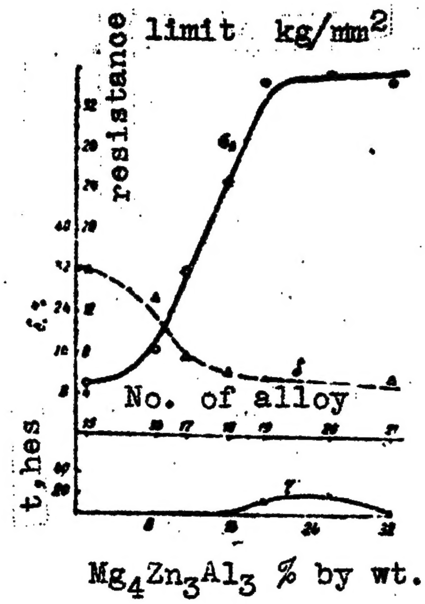


Fig. 3 - Relationship of the heat resistance of the alloys Al-$Mg_4Zn_3Al_3$ to composition. Tests were made of the short-term resistance at 300°, long-term resistance at 300°, with a load of 4 kg/mm^2

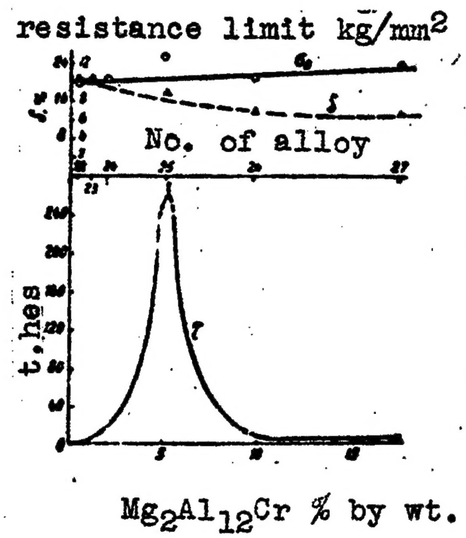
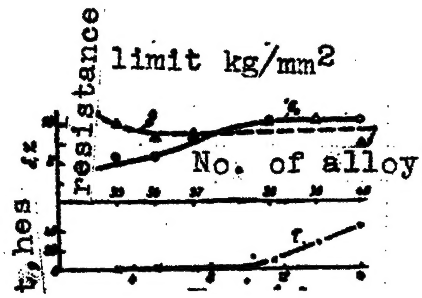
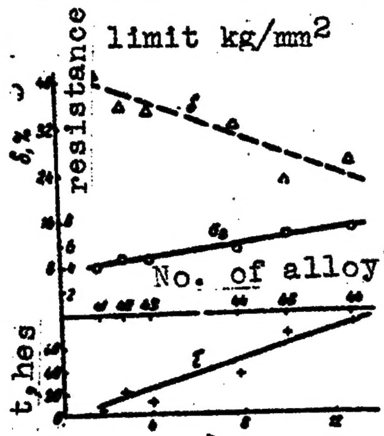


Fig. 4 - Relationship of the heat resistance of the alloys Al-$Mg_2Al_{12}Cr$ to composition. Tests were made of the short-term resistance at 300°, long-term resistance at 300° with a load of 4 kg/mm^2



$Al_{60}Mn_{11}Ni_4$ % by wt.

Fig. 5 - Relationship of the heat resistance of the alloys $Al-Al_{60}Mn_{11}Ni_4$ to composition. Tests were made of the short-term resistance at 300°, long-term resistance at 300° with a load of 4 kg/mm².



Al_9FeNi % by wt.

Fig. 6 - Relationship of the heat resistance of the alloys $Al-Al_9FeNi$ to composition. Tests were made of the short-term resistance at 300°, long-term resistance at 270° with a load of 3 kg/mm²

This does not contradict the work of M. V. Zakharov (15) who showed that in a number of cases the greatest heat resistance was encountered in slightly heterogeneous ternary alloys lying in the quasi-binary sections or close by.

For various systems of this type the higher the maximum of long-term resistance, the greater the high-temperature hardness of the ternary compound and the less the relative decrease in the latter upon increasing the time of exposure to the indentor.

In the remaining systems studied, which are characterized by the absence of noticeable regions of solid solutions, the long term resistance increased linearly with the increase in ternary compound content in the alloy.

The greatest values for short term resistance at 300° were obtained with alloy No 14 of the Al-Cu_3Al_6Ni system (σ_B = 22kg/mm^2; δ = 17%), and alloys Nos. 19-21 of the Al-$Mg_4Zn_3Al_3$ system (σ_B = 35 kg/mm^2; δ = 9-11%), exceeding significantly the resistance of standard heat-resistant deformed alloys (Ak 4-1, VD 17) for which at 300° $\sigma_B \approx$ 16-17 kg/mm^2 and $\delta \approx$ 8-21%.

Alloy No 25 of the Al-$Mg_2Al_{12}Cr$ system had the greatest long-term resistance ; with a load of 4 kg/mm^2 and a temperature of 300° it held for more than 250 hours before fracturing.

Alloys of the Al-$Al_9Si_3Mn_4$ system showed the lowest heat resistance under the test conditions.

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